

State of California
AIR RESOURCES BOARD

EXECUTIVE ORDER D-393-3
Relating to Exemptions Under Section 27156
of the Vehicle Code

JOHNSON MATTHEY
CRT PARTICULATE FILTER

Pursuant to the authority vested in the Air Resources Board (ARB) by Section 27156 of the Vehicle Code; and

Pursuant to the authority vested in the undersigned by Sections 39515 and 39516 of the Health and Safety Code and Executive Order G-45-9;

IT IS ORDERED AND RESOLVED: That installation of the Continuously Regenerating Technology (CRT) Particulate Filter, manufactured by Johnson Matthey of 434 Devon Park Drive, Wayne, Pennsylvania 19087-1889, has been found not to reduce the effectiveness of the applicable vehicle pollution control system, and therefore, the CRT Particulate Filter is exempt from the prohibitions of Section 27156 of the Vehicle Code for installation on heavy-duty on-road vehicles equipped with the following diesel engines:

Engine MY	Engine Make	Engine Model
1991-2001	Caterpillar	3208, 3116, 3126, 3306, 3406, C10, C12, C15, C16 (all horsepower)
1991-2001	Cummins	L10, M11, N14, ISB, ISC, ISL, ISM, ISN, ISX, B-series, C-series (all horsepower)
1991-2001	DDC	Series 40, Series 50, Series 60 (all horsepower)
1991-2001	International	T444E, DT466E, DT466E HT, 530E, 530E HT (all horsepower)
1991-2001	Mack	E7, E9 (all horsepower)
1991-2001	Volvo	VE 275, VE 300, VE 345, VE 385, VE 425, VE 465 (all horsepower)

CRT Particulate Filters exempted under this Executive Order are identified in Attachment A. This exemption applies to 1991 through 2001 model-year 4-stroke engines originally certified to meet a particulate matter emission standard of 0.10 grams per brake-horsepower-hour or lower. This exemption is valid provided that the engines meet the following operating conditions: (1) engine exhaust temperature is greater than or equal to 275° C for 40 to 50 percent of the duty cycle, (2) NO_x to PM ratio is at least 8, and (3) engine is operated using diesel fuel with a maximum sulfur content of 50 parts per million by weight.

This exemption is based on emission tests conducted by Johnson Matthey with the CRT Particulate Filter. Johnson Matthey submitted the following results:

No.	Test Engine			Percent Change in Emissions			
	MY	Make	Model	THC	CO	NOx	PM
1	1999	Caterpillar	3126	-88	-99	-8	-88
2	1995	Cummins	M11	-91	-89	-5	-95
3	1998	DDC	Series 60	-95	-94	2	-87
4	1999	DDC	Series 50	-100	-72	-6	-90

The test data show that the CRT Particulate Filter does not adversely affect the exhaust emissions of the test engines. The same emission impact is expected when the CRT Particulate Filter is installed on heavy-duty vehicles equipped with any of the engines listed above.

This Executive Order is valid provided that installation instructions for the CRT Particulate Filter do not recommend tuning the vehicle to specifications different from those of the vehicle manufacturer.

Changes made to the design or operating conditions of the CRT Particulate Filter, as exempt by the ARB, which adversely affect the performance of the vehicle's pollution control system, shall invalidate this Executive Order.

Marketing of the CRT Particulate Filter using identification other than that shown in this Executive Order or for an application other than that listed in this Executive Order shall be prohibited unless prior approval is obtained from the ARB.

This Executive Order shall not apply to any CRT Particulate Filter advertised, offered for sale, sold with, or installed on a motor vehicle prior to or concurrent with transfer to an ultimate purchaser.

This Executive Order does not constitute any opinion as to the effect the use of the CRT Particulate Filter may have on any warranty either expressed or implied by the vehicle manufacturer.

No claim of any kind, such as "Approved by the Air Resources Board," may be made with respect to the action taken herein in any advertising or other oral or written communication.

In addition to the foregoing, the ARB reserves the right in the future to review this Executive Order and the exemption provided herein to assure that the exempted add-on or modified part continues to meet the standards and procedures of California Code of Regulations, Title 13, Section 2222, et seq.

THIS EXECUTIVE ORDER DOES NOT CONSTITUTE A CERTIFICATION, ACCREDITATION, APPROVAL, OR ANY OTHER TYPE OF ENDORSEMENT BY THE AIR RESOURCES BOARD OF ANY CLAIMS OF THE APPLICANT CONCERNING ANTI-POLLUTION BENEFITS OR ANY ALLEGED BENEFITS OF JOHNSON MATTHEY'S CRT PARTICULATE FILTER.

Violation of any of the above conditions shall be grounds for revocation of this Executive Order. The Executive Order may be revoked only after a ten-day written notice of intention to revoke the Executive Order, in which period the holder of the Executive Order may request in writing a hearing to contest the proposed revocation. If a hearing is requested, it shall be held within ten days of receipt of the request, and the Executive Order may not be revoked until a determination after a hearing that grounds for revocation exist.

Executed at El Monte, California, this 23rd day of May 2001.



R. B. Summerfield, Chief
Mobile Source Operations Division

Attachment A

Table 1

Engine HP	CRT Part No	
	Engine MY 1991-1993	Engine MY 1994-2001
150-230	CRT 1234 IT	CRT 1234 DW
230-330	CRT 1234 MP	CRT 1234 DW
330-425	CRT 1234 NN	CRT 1234 JT
425-660	CRT 1234 MP	CRT 1234 IT

Note: CRT Particulate Filter part number identifies a specific inlet/outlet configuration, catalyst substrate, and filter element based on engine/vehicle combination. CRT Particulate Filters exempted under this Executive Order include 14 different catalyst substrate volume/density combinations and 13 different filter element volume/density combinations. Table 1 identifies the minimum catalyst and filter sizes Johnson Matthey will use on a given engine. Johnson Matthey may use a larger catalyst and/or filter for a given engine/vehicle combination.

State of California
AIR RESOURCES BOARD

EVALUATION OF JOHNSON MATTHEY'S
CRT PARTICULATE FILTER
FOR EXEMPTION FROM THE PROHIBITIONS OF VEHICLE CODE
SECTION 27156 IN ACCORDANCE WITH SECTION 2222, TITLE 13 OF THE
CALIFORNIA CODE OF REGULATIONS

May 2001

by

Mobile Source Operations Division
Aftermarket Parts Section
9528 Telstar Avenue
El Monte, CA 91731-2990

(This report has been reviewed and approved for publication by the staff of the California Air Resources Board. Approval does not signify that the contents necessarily reflect the views and policies of the Air Resources Board. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.)

SUMMARY

Johnson Matthey of 434 Devon Park Drive, Wayne, Pennsylvania 19087-1889 has applied for an exemption from the prohibitions of Section 27156 of the California Vehicle Code for its Continuously Regenerating Technology (CRT) Particulate Filter. The CRT Particulate Filter is designed for installation on heavy-duty vehicles equipped with various model Caterpillar Corporation, Cummins Engine Company, Inc., Detroit Diesel Corporation, International Truck and Engine Corporation, Mack Trucks, Inc., and Volvo Truck Corporation diesel engines. This exemption applies to 1991 through 2001 model-year 4-stroke engines originally certified to meet a particulate matter emission standard of 0.10 grams per brake-horsepower-hour or lower. This exemption is valid provided that the engines meet the following operating conditions: (1) exhaust temperature is greater than or equal to 275° C for 40 to 50 percent of the duty cycle, (2) NO_x to PM ratio is at least 8, and (3) engine is operated using diesel fuel with a maximum sulfur content of 50 parts per million by weight.

Based on the test data submitted by Johnson Matthey, the staff concludes that the CRT Particulate Filter will not adversely affect the exhaust emissions of the heavy-duty diesel engines for which the exemption is requested.

The staff recommends that Johnson Matthey be granted an exemption for its CRT Particulate Filter as requested and that Executive Order No. D-393-3 be issued.

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I. INTRODUCTION

Johnson Matthey of 434 Devon Park Drive, Wayne, Pennsylvania 19087-1889 has applied for an exemption from the prohibitions of Section 27156 of the California Vehicle Code for its CRT Particulate Filter. The CRT Particulate Filter is designed for installation on heavy-duty vehicles equipped with the following diesel engines:

- (1) 1991-2001 model-year Caterpillar 3208, 3116, 3126, 3306, 3406, C10, C12, C15, and C16, all horsepower
- (2) 1991-2001 model-year Cummins L10, M11, N14, ISB, ISC, ISL, ISM, ISN, ISX, B-series, and C-series, all horsepower
- (3) 1991-2001 model-year DDC Series 40, Series 50, and Series 60, all horsepower
- (4) 1991-2000 model-year International T444E, DT466E, DT466E HT, 530E, and 530E HT, all horsepower
- (5) 1991-2001 model-year Mack E7 and E9, all horsepower
- (6) 1991-2001 model-year Volvo VE 275, VE 300, VE 345, VE 385, VE 425, and VE 465, all horsepower

This exemption applies to 1991 through 2001 model-year 4-stroke engines originally certified to meet a particulate matter (PM) emission standard of 0.10 grams per brake-horsepower-hour (g/bhp-hr) or lower. Use of the CRT Particulate Filter requires that the following conditions be met: (1) exhaust temperature is greater than or equal to 275

degrees Celsius ($^{\circ}$ C) for 40 to 50 percent of the duty cycle, (2) NO_x to PM ratio is at least 8, and (3) engine is operated using diesel fuel with a maximum sulfur content of 50 parts per million (ppm) by weight. This exemption includes 14 different CRT catalyst substrate volume/density combinations and 13 different CRT filter element volume/density combinations.

Johnson Matthey has submitted all the required information including emission test data, vehicle operating temperature data, in-use durability information, installation and maintenance procedures, and device identification label for evaluation.

II. CONCLUSION

Based on evaluation of the test data submitted by Johnson Matthey, the staff concludes that the CRT Particulate Filter will not adversely affect the exhaust emissions of the heavy-duty diesel engines for which the exemption is requested.

III. RECOMMENDATION

The staff recommends that Johnson Matthey be granted an exemption as requested, permitting advertisement, sale, and use of its CRT Particulate Filter on the 1991 through 2001 model-year heavy-duty diesel engines listed above.

IV. DEVICE DESCRIPTION AND OPERATION

Johnson Matthey's CRT Particulate Filter is an exhaust emission control device designed primarily to reduce PM emissions from diesel engines. Typically, it is installed in place of the original equipment manufacturer (OEM) muffler. The CRT Particulate Filter is a two-stage modular system that incorporates a precious metal oxidation

catalyst upstream of a wall-flow filter. The catalyst is a Corning or NGK cordierite ceramic monolith designated as EX-20, or equivalent, with an 8-millimeter wall thickness and 300 or 400 cells per square inch (cps) density. It is loaded with Johnson Matthey catalyst loading formulation DF87. The filter element is also a Corning or NGK cordierite ceramic monolith designated as EX-80, or equivalent, with a 17-millimeter wall thickness and 100 or 200 cps density. The filter is porous and has alternating cells that are plugged which force the exhaust gas to flow through the cell wall where PM in the exhaust gas is trapped. The catalyst and filter elements approved under this exemption are identified by Table 1 and the notation below:

Table 1

Engine HP	CRT Part No.	
	Engine MY 1991-1993	Engine MY 1994-2001
150-230	CRT 1234 IT	CRT 1234 DW
230-330	CRT 1234 MP	CRT 1234 DW
330-425	CRT 1234 NN	CRT 1234 JT
425-660	CRT 1234 MP	CRT 1234 IT

Note: CRT Particulate Filter part number identifies a specific inlet/outlet configuration, catalyst substrate, and filter element based on engine/vehicle combination. CRT Particulate Filters exempted under this Executive Order include 14 different catalyst substrate volume/density combinations and 13 different filter element volume/density combinations. Table 1 identifies the minimum catalyst and filter sizes Johnson Matthey will use on a given engine. Johnson Matthey may use a larger catalyst and/or filter for a given engine/vehicle combination.

As the exhaust gas flows through the CRT system, a fraction of the nitric oxide (NO) in the engine exhaust is oxidized to nitrogen dioxide (NO₂) in the catalyst section. NO₂ then reacts with the soot collected on the filter element and combusts it at a much

lower exhaust temperature than is needed in an oxygen environment. Combustion of soot regenerates the filter, preventing plugging. For the CRT system to be effective, the NOx to PM ratio must be at least 8 and the engine exhaust temperature must be 275° C or higher for at least 40 to 50 percent of the duty cycle. In addition, the CRT system must be used with diesel fuel with a maximum sulfur content of 50 ppm by weight to minimize oxidation of SO₂ for optimum NO to NO₂ conversion.

Prior to retrofitting a vehicle with the CRT system, Johnson Matthey will review the engine model-year and compare the applicable new engine NOx and PM emission standards to verify that the NOx to PM ratio is at least 8. Johnson Matthey will equip the vehicle with thermocouples and record the engine exhaust temperatures while the vehicle is operated over its typical duty cycle to confirm that the exhaust temperature requirement is met. Johnson Matthey will also refer to its database of exhaust temperatures and review it for similar engine and vehicle applications to ensure that the temperature requirement is met. Using this information, Johnson Matthey will design a CRT system properly matched for a specific engine and vehicle application. Proper sizing of the catalyst and filter for an application will be based on engine size or exhaust flow rate, particulate loading or engine-out PM emissions, backpressure requirement, engine exhaust temperature (vehicle application or duty cycle), and availability of space for the CRT system.

The installation location of the CRT system varies for different vehicle applications, but on the average, the distance between the exhaust port and the system inlet ranges from three to 25 feet. For vehicles with dual exhaust system, a CRT system is installed on each of the exhaust pipes. The installation procedures for the CRT system are similar to the removal and installation procedures for the muffler.

Johnson Matthey recommends that a backpressure reading be taken every 25,000 miles and compared against the limits specified by the OEM. If the backpressure exceeds the specified limit, the filter should be cleaned and re-installed in the reverse direction. The catalyst element can also be cleaned and reversed in order to reduce engine backpressure. Johnson Matthey will provide the applicable installation instructions and maintenance procedures for the various engine and vehicle combinations to the vehicle operator.

V. DEVICE EVALUATION AND DISCUSSION

To demonstrate that the CRT system does not adversely affect exhaust emissions, Johnson Matthey tested the system on five engines and provided the following test results:

Test Engine			Test Fuel		Emissions: Baseline/Modified			
MY	Make	Model	Sulfur	Test Cycle	THC	CO	NOx	PM
1999	Caterpillar	3126 ¹	15 ppm	FTP Hot*	0.06/0.01	1.32/0.01	3.6/3.3	0.077/0.009
1995	Cummins	M11 ²	15 ppm	CSHVR**	1.24/0.11	2.89/0.32	14.7/13.9	0.562/0.026
1998	DDC	Series 60 ³	54 ppm	FTP	0.11/0.01	1.20/0.08	3.8/3.9	0.063/0.008
1998	DDC	Series 60 ⁴	15 ppm	CSHVR	0.26/0.00 [^]	6.81/0.12	34.5/35.3	0.211/0.003
1999	DDC	Series 50 ⁵	15 ppm	FTP	0.04/0.00	0.63/0.17	3.4/3.2	0.089/0.009

Notes: ¹ 7.2 liter, 300 horsepower
² 10.8 liter, 330 horsepower
³ 12.7 liter, 400 horsepower
⁴ 12.7 liter, 430 horsepower
⁵ 8.5 liter, 277 horsepower

* FTP emissions in grams per brake-horsepower-hour
** CSHVR emissions in grams per mile
[^] Emissions were below detectable limit

Caterpillar 3126, DDC Series 60, and DDC Series 50 engines were tested on an engine dynamometer using the heavy-duty diesel transient Federal Test Procedure (FTP). One baseline emission test was conducted with the engine in the OEM

configuration, and one modified emission test was conducted with the CRT system.

The Caterpillar 3126 emission data are for the hot start portion of the FTP.

Cummins M11 and a second DDC Series 60 engines were tested on a mobile chassis dynamometer operated by the West Virginia University using the transient City Suburban Heavy Vehicle Route (CSHVR) drive cycle. The CSHVR drive cycle represents the typical driving pattern of a vehicle on an urban delivery schedule. The route is approximately 6.7 miles long, and the drive cycle speed ranges from 0 to 45 miles per hour. For the Cummins M11 tanker truck, baseline and modified emission results reported are average emissions from two test vehicles, and each vehicle test included a minimum of three emission runs. For the DDC Series 60 grocery truck, the emissions are average emissions from five test vehicles. For the DDC Series 60 grocery truck, two different sets of five test vehicles were used for the baseline and modified emission tests. The ten test engines and vehicles were determined to be nominally identical to each other (e.g. identical model-year, engine, chassis configuration, and equipment). For the Cummins M11 and DDC Series 60 trucks, each test run with the CRT system consisted of a double-length CSHVR drive cycle (13.4 miles) to facilitate collection of sufficient PM for measurement.

Emission Evaluation

PM removal from engine exhaust is fixed by the physical characteristics of the filter medium and is relatively unaffected by engine operating conditions. The engines for which the exemption is requested have been certified to PM emission standards ranging from 0.05 to 0.10 g/bhp-hr. To demonstrate compliance with the emission requirements, Johnson Matthey submitted emission test data for five engines. All of the test engines were originally certified to meet the 0.10 g/bhp-hr PM emission standard,

representing worst case in terms of engine-out PM emissions. All of the engines were tested with the lower density filter element. When the filter cell density is increased, the available surface area for the exhaust gases to pass through is also increased. This in turn increases the capability of the filter to collect PM. On a filter with a higher cell density, the thickness of accumulated PM layer is thinner than on a filter with a lower cell density and equivalent soot loading. The thinner PM layer results in lower backpressure. The filters tested represent worst case in terms of filtration efficiency and effect on backpressure.

The emission data showed that when the engines with the CRT system were tested using diesel fuel with sulfur content between 15 and 54 ppm, there was no adverse impact on total hydrocarbons, carbon monoxide, oxides of nitrogen, or PM emissions. The same emission impact is expected when the CRT system is used on any of the engines included in the exemption and operated using diesel fuel with a maximum sulfur content of 50 ppm.

CRT Filter Regeneration

The soot collected in the filter element must be burned off or oxidized to regenerate the filter and prevent plugging. For "continuous" regeneration of the filter, there must be sufficient amount of NO₂ and the engine must operate at a temperature of 275° C or higher for at least 40 to 50 percent of the duty cycle. All of the engines were tested with the lower density catalyst substrate. An increase in the catalyst cell density increases the number of active sites for catalytic reaction, thereby increasing the overall catalyst activity. The catalysts tested represent worst case in terms of NO to NO₂ conversion.

For an application where the engine exhaust temperature is below the 275° C threshold for a prolonged period of time, there may not be enough combustion of soot, and the filter may become plugged. This will lead to excessively high backpressure and may cause damage to the turbocharger and/or the engine. Such low temperature conditions may be encountered in a large engine operating under low load or in an engine operated under a duty cycle that requires frequent stop-and-go and idling.

To demonstrate that the minimum temperature threshold for soot combustion is reached and maintained for sufficient duration in engines and vehicle applications for which the exemption is requested, Johnson Matthey measured the exhaust gas temperatures of six different engines while they were operated on-road under various duty cycles. Johnson Matthey provided the following results:

Test Engine				Application	Exhaust Temperature (° C)		% Time
Make	Model	Size (L)	HP		Minimum	Maximum	Temperature Over 275°C
Cummins	ISM	N/A	N/A	Sanitation Truck	125	425	55
Cummins	ISC	8.3	N/A	School Bus	200	425	60
Cummins	M11	10.8	N/A	Delivery Truck	125	425	60
DDC	Series 60	12.7	430	Delivery Truck	125	450	55
DDC	Series 50	8.5	277	City Bus	125	400	80
International	466	7.6	N/A	School Bus	175	500	65

The temperature data showed that the engine exhaust temperatures were above the 275° C threshold for well over 50 percent of the typical city and highway duty cycles represented by the test vehicles. With respect to exhaust temperatures, city buses and sanitation trucks represent the worst case duty cycles due to their frequent stop-and-go and idling, and under such conditions, Johnson Matthey showed that the

exhaust temperature needed for soot combustion is reached and maintained for sufficient period of time.

To further illustrate that the CRT system operates properly on-road, Johnson Matthey cited test programs in which numerous units are currently or have been in-use and provided the following to address the long-term operability of the CRT filter:

Test Program	No. of Units	Duration of Operation	Approximate Miles of Operation
New York City Transit Buses	25	1 year	35,000
ARCO Tanker/Ralphs Grocery Trucks	10	1 year	100,000
LA Sanitation Trucks	5	1 year	10,000
San Diego School Buses	5	1 year	30,000
European Testing	N/A	3-5 years	66,000-373,000

The horsepower ratings of the engines for which the exemption is requested range from 150 to 600 horsepower. The staff concludes that the test engines above are representative of the engines included in the exemption application and expects that similar emission and temperature results will be achieved for the remaining engines and vehicle applications. Based on these findings, the staff concludes that Johnson Matthey's CRT Particulate Filter will not have any adverse impact on the exhaust emissions of the engines included in the exemption.